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REPORT

CD NO.

50X1-HUM

COUNTRY	USSR	DATE OF INFORMATION	1948
SUBJECT	Scientific - Metals, steel, ball-bearing	DATE DIST.	17 Apr 1951
HOW PUBLISHED	Monthly periodical		
WHERE PUBLISHED	Moscow	NO. OF PAGES	7
DATE PUBLISHED	Jun 1948	SUPPLEMENT TO REPORT NO.	
LANGUAGE	Russian		

THIS IS UNEVALUATED INFORMATION

SOURCE Stal', No 6, 1948, pp 511-520

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MANUFACTURE OF BALL-BEARING STEEL IN THE USSR

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Ball-bearing steel ShKh15 has been produced in the USSR for a period of over 20 years, but the technology of its production still contains some controversial points. This article deals with an analysis of the technological practice established in the Kuznetsk Metallurgical Combine.

A. Smelting Process For ShKh15

Basic electric-arc furnaces of 30-ton capacity are used for smelting ShKh15 steel in the Kuznetsk Combine. The transformer capacity is 8,000 kva. Dinas or sometimes chrome-magnesite brick is used for roofs, and magnesite brick spaced with soft sheet iron is used for walls. The hearth is lined with magnesite, with water glass as a binder. The thickness of the lining in a new furnace is 150-200 mm. Charging machines are employed in the cold-charge process.

In smelting ShKh15 steel with oxidation, the charge consists mostly of open-hearth steel scrap. Coke is used for recarburizing instead of pig iron, in order to avoid introduction of considerable amounts of phosphorus and silicon.

In smelting steel by the remelting method, the charge is made of ShKh15 scrap or scrap from structural 20 Kh-40 Kh steels without the addition of soft carbon steel. The moisture content in generator black (used instead of coke fines for making the reducing slag), lime, fluorspar, and iron ore must be maintained at less than 2%. Usually it is equal to or lower than 0.4-0.5%. Ore and fluorspare are dried in drying ovens heated with blast-furnace gas.

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1. Oxidizing Period

The boiling process, in smelting ShKh15 steel with oxidation, may be characterized by the amount of carbon burning out, the burning-out rate of carbon, the total time of the boiling process, behavior of manganese, and temperature conditions during the oxidizing period.

According to technological instructions, the carbon content in metal has to be 1.0-1.4% at the end of melting, and 0.75-0.80% at the end of boiling. A considerable number of heats has been investigated for the purity of metal in relation to oxide inclusions and gas content. Results show that contamination of metal increases when an insufficient amount of carbon is burned out. On the other hand, increasing the amount of carbon burning out above 0.40% promotes no further refining of the metal from oxide inclusions and does not decrease the gas content.

The carbon burning-out rate is given by technological instructions as 0.25-0.60% C per hr, while a rate of 0.80% C per hr is acceptable for the period between two consecutive samplings. Observation of the process shows that extremely intensive boiling with a burning-out rate higher than 0.60% C per hr promotes the gas content in metal; however, at the same time, the number of heats with highest degree of contamination with inclusions decreases considerably.

There is no suggestion given in smelting technology for the proper content of manganese during the oxidizing period. The increased content of manganese at the end of boiling hardly provides for obtaining oxide-free ShKh15 steel, since the high content of carbon satisfactorily prevents excessive oxidation of the metal and, consequently, its contamination with oxide inclusions.

It seems that greater significance may be assigned to the manganese content immediately after melting the charge in the beginning of the oxidizing period, when a high content of manganese promotes more intensive fluxing of silica with manganous oxides into low-melting coarse particles of manganese silicates which enter the slag.

The ratio Mn:S in the charge must be kept in the range from 7 to 4. The necessary value of this ratio has to be secured by the addition of ferromanganese, if killed steel scrap was used for making the charge.

The temperature of the boiling period must be sufficiently high, since only this condition gives steel free of inclusions. The temperature is normal when 0.010-0.0125% Mn is oxidized for each 0.01% burned-out carbon. If, for example, 0.30% C is eliminated during the boiling period, manganese must be oxidized in an amount from 0.30 to 0.37%. More intensive oxidation of manganese shows that the temperature of a bath is too low and vice versa. Observations of a great many heats proved that cold heats are considerably more contaminated with impurities and contain more gases, compared to heats with normal temperature during the boiling period.

It may be concluded that the manganese content in metal during the oxidizing period has no effect on the final quality of ShKh15 steel, but the oxidation rate of manganese during this period must be in definite relation with the burning-out rate of carbon.

2. Reducing Period

Refining begins with the formation of slag from lime, fluorspar, and crushed dinas in the ratio of 10:2.5:1. On the basis of preliminary testing, ferromanganese may be added in the amount calculated for the lower limit of manganese content.

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After another sample has been taken, the carbide mixture of lime, fluorspar, crushed dinas, and generator black in a ratio of 8:2:1:8 is introduced into molten metal and the furnace is tightly closed for 25-30 min, after which period ferrochrome is added in the amount calculated for the lower limit of the chromium content.

After melting the ferrochrome and taking the samples, the reducing slag is deoxidized with a mixture of lime, generator black, and powdered ferrosilicon in the ratio of 4:1:2, by spreading this mixture in small portions over the entire surface of the molten bath. The total consumption of ferrosilicon powder by diffusion deoxidation amounts to 5-6 kg per ton.

If sufficiently active carbide slag is formed in the furnace at the beginning of the reducing process, the generator black may be decreased in quantity or omitted entirely.

The carbon content must be controlled by the proper grade of ferrochromium. Only as a last resort is it permissible to add a small amount of pig iron, not more than 6-7 kg per ton, and at least 20 min must elapse from the time it is added to the time of tapping the melt.

The content of ferrous oxide in the finishing slag must not be higher than 1%.

Sometimes a small addition of lump ferrosilicon is necessary before tapping. Aluminum in the amount of 0.3 kg per ton has to be added 2-3 min before tapping, which operation must be performed under the white slag.

The refining period varies from 1 hr, 40 min to 2 hr, 20 min; the temperature of metal in the spout amounts to 1,500-1,510°.

Complete deoxidation of reducing basic slags is very essential for obtaining a low content of sulfur in electric steel.

The refining period must be sufficiently long for completing the process of diffusion of inclusions from metal to the slag phase. However, it cannot be exceedingly delayed without the risk of a high gas content. Best results may be achieved with a reducing period not longer than 2 hr.

B. Steel Pouring

All ShKh15 steel is poured by the rising method, the weight of ingots being equal to 1,390 kg. Since the end of 1946, experiments have been conducted for pouring 6-ton ingots, the size accepted for other grades of steel. The expediency of pouring 6-ton ingots of ball-bearing steel and the quality of metal thus obtained still require elaborate investigation. The temperature of the molten metal and the pouring time for ingots of ShKh15 steel are as follows:

	Temp of Metal (°C)			Pouring Time (sec)		
Wt of Ingot (tons)	In Spout	At Beginning of Pouring	At End of Pouring	To the Head	Head with Replenishment	Total
1.39	1,510-1,505	1,450-1,445	1,430-1,425	180-240	90-120	270-360
6	1,510-1,505	1,450-1,445	1,435-1,430	240-300	180-240	420-540

C. Rolling ShKhl5 Steel

Ingots, as a rule, are delivered to the soaking pit in a hot state, each pit being loaded with six ingots. Temperature conditions for heating the ingots are maintained as follows:

Temp of Incoming Ingots (°C)	Heating Time (hr-min) 1st Per	2d Per	3d Per	Total	Temp of Outgoing Ingots (°C)
640-650	1:10	5:30	1:30	8:10	1,235
700-740	1:25	3:10	1:55	6:30	1,225
750-820	0:30	3:20	1:30	5:20	1,225

Heated ingots of 690 x 535-mm size, delivered to the blooming mill with 1,100-mm roll diameter, are reduced to a cross section of 350 x 320 mm in 19 passes.

The absolute reduction varies from 30 mm in the first passes to 62 mm in the last pass. In contrast to ShKhl5 steel, all other steels are rolled in 11-13 passes with 40-60 mm reduction in initial passes and 130 mm for the last ones. Reduction conditions established for ShKhl5 steel provide for satisfactory surface of blooms and prevent excessive internal stresses.

Blooms with a cross section of 350 x 320-mm, with a temperature of 850-860°, go into pits for slow cooling to 150-130° over a period of 72 hours.

Small ingots and blooms rolled from large ingots are inspected, their surface quality being evaluated according to special scales standard at the plant. They are divided into three categories for ingots and five categories for blooms, all defects being marked. Pneumatic hammers and emery wheels are used to eliminate defects.

Recently experiments have been conducted on flame-scarfing ingots of ShKhl5 steel. Because of the possibility of crack formation, the metal has been preheated to various temperatures.

Experiments revealed that ingots and blooms of ShKhl5 steel must be preheated before torch scarfing at least to 450°, otherwise cracks may appear on the surface of billets after rolling even if there were no such cracks on ingots and blooms.

Blooms and 1,390-kg ingots are rolled on blooming mill 750, for which purpose they are heated in three-zone gas furnaces, in conformity with a prescribed heating procedure:

	Ingots	Blooms
Temp in the entering end (°C)	650	650
Time of heating (hr-min)	4-00	4-00
In holding zone of furnace	2-15	3-00
In welding zone	1-30	1-00
In soaking zone	8-15	8-00
Total		
Temp of metal at outgoing end	1,140-1,160	1,140-1,160
Heating rate (min/cm)	12.3	15.0
No of ingots or blooms in each outgoing batch	4	8
Time between two outgoing batches (min)	45	60

Uniformity of heating must be observed by all means, and overheating must be avoided.

Even the slightest deviations from the established heating procedure may be detrimental to the quality of ShKh15 steel. On reaching a temperature of 700-750°, the steel may be heated at any rate in the welding zone of the furnace. During this period, the temperature of the metal must be brought as nearly as possible to the rolling temperature.

The subsequent soaking period, significant in the case of any metal, is especially essential for ShKh15 steel. The heating temperature and soaking are in close relation, and the slightest change in one of these factors without corresponding modification of the other factor may lead to deterioration of the metal.

During the soaking period, diffusion processes occur in the metal, promoting dispersion of carbide segregations. The heating procedure established in the plant secures complete diffusion of carbide segregations and, as a result, the finished grade of ShKh15 steel has a very low value for carbide liquation.

In addition, soaking metal at high temperatures decreases, to a certain extent, its tendency to form flakes. Uniformity in heating prevents ShKh15 steel from many defects in rolling, some of these defects being erroneously related to the smelting process. However, a prolonged soaking period at high temperatures increases scaling and decarburization and also may lead to overheating and burning. Scale of metal causes the formation of hair cracks, especially in hard grades of metal.

Overheating and burning sometimes affect ShKh15 steel differently from other steels, causing, in some cases, a particular defect, black dots, which are usually revealed in the central part of sections after etching them with a 30-50% solution of hydrochloric acid. Sometimes the black dots are accompanied by a coarse porosity which resembles traces of a shrinkage cavity. Black dots occur in heating and rolling mainly the ShKh15 steel. They may be created purposely by heating a 1,390-kg ingot to 1,215-1,250° for 16 hr with subsequent mechanical working.

The occurrence of black dots may be explained by penetration of oxidizing furnace gases into ingots through intercrystalline cracks which often develop in overburned alloy steels. If the temperature inside an ingot is very high and the more fusible constituent of steel is melted uncovering grain boundaries, the oxidizing action of furnace gases deprives the crystals of their cohesiveness in rolling and, as a result, black dots appear. The extent of overburning may vary in the process of hot mechanical working. Apparently, black dots represent the initial stage of overburning.

Investigation of metal in heating and rolling billets on a 450 mill shows that:

1. In heating sound billets of ShKh15 steel at any temperature, the black dots do not appear until complete overburning is reached, when billets deteriorate and go to pieces in rolling.

2. On normal heating of billets previously affected by black dots, the dots do not disappear in subsequent rolling into shapes, but neither are they further developed.

3. On exceedingly high heating and long soaking of billets affected by black dots, this defect develops further, and shapes produced by rolling such billets may have voids and flaws.

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Black dots mainly affect first ingots located near the flame of frontal burners. They disappear entirely after decreasing the soaking period from 1 hr 40 min to 45 min, and lowering the heating temperature from 1,180 to 1,160°.

After rolling, the metal has to be cut and cooled. Metal rolled from ingots is cooled in slow cooling pits and metal from blooms, in stacks.

The following conditions are maintained for pit cooling of billets after rolling on a 750 mill:

Temp of pits before loading (°C)	130
Temp of metal on loading in pits (°C)	750
Temp of metal before opening lids of pits (°C)	400
Temp of metal at discharge from pits (°C)	130
Time of cooling metal with closed lid to 400° (hr)	12
Time of cooling with open lid to 130° (hr)	4-24

The cooling rate of pits with open lids varies, depending on the season of the year and the extent of loading adjacent pits with hot metal.

Metal cooled below 650° before loading into pits often develops flakes. Therefore, the process of cooling the billets of ShKh15 steel is a very essential operation. Proper cooling conditions entirely prevent formation of flakes.

Cooled billets, after surface conditioning by chipping or grinding, are rerolled into shapes in section mills 450 and 360. Again heating conditions have to be observed thoroughly to avoid decarburization, the basic defect of ball-bearing steel. The heating conditions are as follows:

Cross Section of a Sq Billet (mm)	Temp of Entering Part (°C)	Time of Heating in Holding and Welding Zones	Time of Heating in Soaking Zone	Total Time of Heating (hr-min)	Temp of Metal on Going Out	Heating Rate (min/cm)
80 x 80 - 100 x 100	700	1-30	0-10	1-40	1,080 - 1,100	11.0
125 x 125 - 140 x 140	700	2-00	0-25	2-25	1,080 - 1,100	11.6-10.3
160 x 160	700	2-45	0-25	3-10	1,080 - 1,100	11.9

Large shapes of ball-bearing steel of 120-80 mm diameter are rolled from 160 x 160-mm billets, shapes of 80-52 mm diameter from 140 x 140-mm billets; 120 x 120-mm billets are used for rolling all smaller shapes.

Laboratory control of finished grades of ShKh15 steel manufactured in the Kuznetsk Combine during one year gave satisfactory results.

The following was the distribution of heats:

1. According to the content of nonmetallic inclusions:

Inclusion evaluation	1-1.5	2-2.5	3.0	>3.0
No of heats (%)				
Oxides	43.3	49.5	7.1	0.1
Sulfide	28.8	67.8	3.4	-

2. According to carbide liquation:

Evaluation number	0	0.5	1.0	1.5	>1.5
No of heats (%)	68	23.7	6.4	1.1	0.8

3. According to Porosity (by Leningrad scale, in which the densest metal is evaluated by 1):

Evaluation number	1-1.5	2.0	2.5	3.0	>3.0
No of heats (%)	7.4	71.9	13.8	6.8	0.1

Flakes were revealed in 1.24% of heats.

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